Table 6. Predicted response to policies for a 10% reduction in regional drainage

		Base Case	Drain Tax	Water Market
Cotton				
Acres	(% total)	66%	69%	67%
Applied Water	(feet)	3.33	3.23	3.18
Irrigation Efficiency	(%)	73%	77%	75%
Irrig. tech & mngmt costs	($/acre)	91.94	107.96	98.18
Yield	(tons/acre)	0.62	0.62	0.64
Melons				
Acres	(% total)	6%	4%	6%
Applied Water	(feet)	1.90	1.83	1.87
Irrigation Efficiency	(%)	67%	70%	68%
Irrig. tech & mngmt costs	($/acre)	62.84	72.59	64.58
Yield	(tons/acre)	8.83	9.01	8.85
Sugarbeets				
Acres	(% total)	3%	7%	3%
Applied Water	(feet)	4.24	4.60	4.07
Irrigation Efficiency	(%0)	80%	75%	84%
Irrig. tech & mngmt costs	($/acre)	118.76	103.84	133.15
Yield	(tons/acre)	30.82	29.92	30.91
Tomatoes				
Acres	(% total)	9%	9%	9%
Applied Water	(feet)	3.27	3.10	3.25
Irrigation Efficiency	(%)	78%	82%	77%
Irrig. tech & mngmt costs	($/acre)	108.28	128.14	106.61
Yield	(tons/acre)	32.69	32.89	32.70
Wheat				
Acres	(% total)	7%	7%	7%
Applied Water	(feet)	2.38	2.29	2.14
Irrigation Efficiency	(%)	68%	72%	74%
Irrig. tech & mngmt costs	($/acre)	62.73	72.75	75.03
Yield	(tons/acre)	3.02	3.02	3.03
Fallow Acres	(% total)	5%	3%	8%
Collected drain water	(af/acre)	0.45	0.41	0.41
Collected drain water	(af/drained acre)	0.89	0.62	0.62
Water Sales	(af/acre)	na	na	0.31
Crop Returns	($/acre)	339.40	336.92	336.85
Net Returns	($/acre)	339.40	297.30	359.02

Table 7. Predicted response to policies for a 20% reduction in regional drainage

			Drain Tax		Water Market	Crop-specific Water Tax		Uniform Water Tax
Policy Instrument:		Pd	131.96	Pm	88.00	Tw 92(1:2:.5)	Tw	87.45
Cotton								
Acres	(% total)		70%		61%	56%		60%
Applied Water	(feet)		3.18		3.01	2.96		2.99
Irrigation Efficiency	(%)		78%		78%	79%		78%
Irrig. tech & mngmt costs	($/acre)		112.98		108.48	111.67		109.66
Yield	(tons/acre)		0.63		0.64	0.64		0.64
Melons								
Acres	(% total)		5%		6%	4%		8%
Applied Water	(feet)		1.83		1.78	1.40		1.79
Irrigation Efficiency	(%)		70%		70%	80%		69%
Irrig. tech & mngmt costs	($/acre)		74.02		70.73	103.64		69.44
Yield	(tons/acre)		9.03		8.82	8.70		8.65
Sugarbeets								
Acres	(% total)		7%		2%	8%		2%
Applied Water	(feet)		4.40		3.91	4.63		3.87
Irrigation Efficiency	(%)		78%		87%	74%		88%
Irrig. tech & mngmt costs	($/acre)		113.12		148.79	93.47		153.65
Yield	(tons/acre)		30.10		32.46	29.88		32.80
Tomatoes								
Acres	(% total)		8%		9%	9%		8%
Applied Water	(feet)		3.06		3.13	3.10		3.11
Irrigation Efficiency	(%)		83%		80%	81%		81%
Irrig. tech & mngmt costs	($/acre)		132.03		118.84	122.08		120.95
Yield	(tons/acre)		32.71		32.70	32.69		32.69
Wheat								
Acres	(% total)		7%		7%	7%		7%
Applied Water	(feet)		2.18		2.03	2.00		2.03
Irrigation Efficiency	(%)		74%		78%	79%		78%
Irrig. tech & mngmt costs	($/acre)		77.75		84.59	86.79		85.09
Yield	(tons/acre)		3.02		3.04	3.03		3.05
Fallow Acres	(% total)		3%		15%	16%		16%
Collected Drain Water	(af/drained acre)		0.55		0.55	0.55		0.55
Water Sales	(af/ac)		na		0.65	na		na
Crop Returns	($/acre)		332.64		308.23	307.42		302.84
Net Returns	($/acre)		284.87		365.73	89.36		93.81

Note: Values for crop-specific water tax are: $92/af for cotton, tomatoes and wheat, $184/af for melons, and $46/af for sugarbeets taxes for each input, and a uniform input tax in terms of marginal information costs and efficiency benefits. A water market price of $88/af is found to result in the desired reduction in collected drain water. A value of $87/af accomplishes the same objective with a uniform water tax.

The difference in the values of the water market and water tax parameters is somewhat surprising. These instruments provide the same incentive regarding water conservation and therefore one would expect that the same value would be required to achieve the drainage reduction objective. The difference is that the initial allocative inefficiency of existing water supply institutions is corrected in the case of the water market but not with the water tax. More drainage is created in some areas as a result of the initial reallocation of water resources, so a slightly higher level for the instrument is necessary to motivate the 20% drainage reduction with a water market than with a uniform water tax.

In contrast to the drain tax, the water market and a uniform water tax motivate significant changes in cropping patterns. The reason for this is clear; water markets create a general incentive to reduce water use while drain taxes act as an incentive to conserve only that quantity of water applied in excess of crop needs. Thus, a crop such as melons that has a relatively high marginal value product of water is favored under a water market despite the fact that it tends to be irrigated less efficiently with a relatively high marginal drain water product. Sugarbeets, a high water using crop, is phased out under a market, but not in response to a drain tax.

A crop-specific water tax may also be specified to account for variation in drainage production that arises when water is applied to different crops. The tax examined here varies in proportion to the marginal drain water product of water for each crop, evaluated at optimal levels. The marginal drain water product for water used on melons is predicted to be twice that of water used on cotton. This value is approximately the same for tomatoes and wheat as for cotton, but is roughly two times as great as that for water used to produce sugarbeets. The tax examined is thus specified as $92/af for water used to produce cotton, tomatoes or wheat, $184/af for water used on melons and $46/af for water used on sugarbeets. Table 7 includes results from these scenarios.

As predicted, water market and uniform water taxes create an incentive to increase melon acreage and reduce acres allocated to sugarbeets, relative to the drain tax scenario. One advantage of the crop-specific water taxis that it reduces distortionary crop allocation incentives inherent in the uniform tax. Melons are predicted to occupy 5% of total acres under a drain tax, 4% with crop-specific water taxes, 6% under a water market and 870 with a uniform water tax. In contrast, sugarbeets represent 7% and 8% of the acreage in response to a drain tax and crop-specific water taxes, respectively, but only 2% of the acreage under a water market or uniform water tax. All three of the less efficient policies create incentives to reduce cotton acreage, which declines by 13% to 20%, and to increase the quantity of fallow land.

Predicted irrigation efficiencies are generally constant across policies. There are two exceptions: melons are irrigated at higher efficiencies with the crop-specific water tax than with other policy instruments; and, the water market and uniform water taxes result in irrigation efficiencies on sugarbeets that are 14% to 15% higher than the level implied by the optimal solution.

Crop returns (efficiency benefits) and fiscal implications associated with the policies considered are summarized in Figure 1. The efficiency costs of the water market and crop-specific water tax policies are $25 and $26 per acre, respectively. A uniform water tax is the least efficient policy considered with an efficiency cost of $30/acre.

It is interesting to note that the water market, which in effect represents a uniform water charge, results in crop returns that are slightly higher than under a water tax that incorporates variation in drain water production of crop-specific water use. The explanation for this lies in the inefficiencies created by current water supply institutions which are eliminated through the inter-district water market but which remain in place with a uniform water tax. These results provide empirical support for conclusions regarding the second-best implications of the institutional setting in the drainage problem area discussed in a companion paper.

Thirty Percent Drainage Reduction

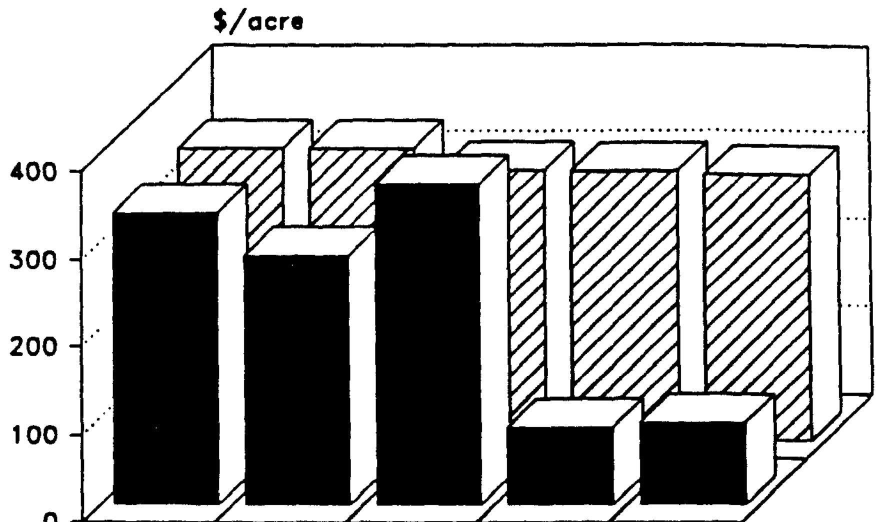
The thirty percent drainage reduction objective is significant in that it is the value suggested to be sufficient to achieve San Joaquin River water quality standards, as previously discussed. Simulation results for policies designed to achieve this objective are presented in Table 8. Results indicate a minimum cost of meeting the thirty percent drainage reduction objective of $14/acre. A drain tax of $190 per acre foot of collected drain water generates this result.

The San Joaquin River Basin Technical Committee that proposed the thirty percent reduction objective suggested that this objective could be achieved by increasing irrigation efficiencies in the study area to 80% (California, 1987). A policy of mandating irrigation efficiency levels was therefore included in this analysis. An irrigation efficiency standard of 83% was found to generate a thirty percent reduction in drain water volumes. Results from this analysis are included in the second column of Table 8. The efficiency cost of this policy is $8/acre.

Policies that combine uniform water taxes with subsidies for improving irrigation efficiency were also considered. There are many combinations of values for these instruments that will yield the desired drainage reduction, though none achieves the objective at least cost. Two combinations are shown here: a $45/af water tax combined with a 45% irrigation system cost subsidy and a $75/af water tax and 25% subsidy combination. Predicted responses to these policies are presented in the last two columns of Table 8.

The irrigation efficiency standard generates results that are very similar to the optimal solution in all respects except for those results describing irrigation management on melons. This is an important exception, however. Melons represent a production process with high marginal abatement costs in this analysis. Difficulties associated with improving irrigation efficiencies on melons are reflected in irrigation system costs for this crop that are $37/acre higher under the 83% efficiency standard than is optimal. According to economic theory, it is not optimal to require identical abatement levels from sources with different costs. Rather, optimality requires relatively more abatement from sources lower costs and less from the higher cost processes so that Bmarginal abatement costs are equated across sources. This principle is reflected in the results of the drain tax scenario in which melons are irrigated less efficiently than other crops. The inefficiencies created by standards on irrigation efficiency levels arise because there is no flexibility in the instrument to account for these factors.

Figure 1. Crop returns and fiscal effects of alternative policies for achieving a 20% reduction in drain water



	Standard	Tax	Water Market	Water Tax by Crop	Uniform Water Tax
Crop Returns	333	333	308	307	303
Fiscal Cost	0	-48	58	-218	-209
Net Returns	333	285	366	89	94

Table 8. Predicted response to policies for a 30% reduction in regional drainage

	Drain Tax	Irrigation Efficiency Standard	Water tax/ Irrigation Efficiency Subsidy	
Policy Instrument:	Pd: $191.38/af cdw	IE: 83%	Tw: $45/af	$75/af
			S: 45%	25%
Cotton				
Acres (% total)	69%	69%	72%	67%
Applied Water (feet)	3.09	2.93	2.94	2.90
Irrigation Efficiency (%)	81%	83%	84%	82%
Irrig. tech & mngmt costs ($/acre)	123.60	129.67	134.37	126.81
Yield (tons/acre)	0.63	0.62	0.62	0.63
Melons				
Acres (% total)	5%	4%	5%	6%
Applied Water (feet)	1.83	1.72	1.68	1.71
Irrigation Efficiency (%)	71%	83%	77%	74%
Irrig. tech & mngmt costs ($/acre)	76.93	114.27	94.50	82.98
Yield (tons/acre)	9.04	9.13	9.05	8.84
Sugarbeets				
Acres (% total)	7%	8%	7%	3%
Applied Water (feet)	4.19	4.06	3.98	3.71
Irrigation Efficiency (%)	82%	84%	86%	92%
Irrig. tech & mngmt costs ($/acre)	126.43	133.49	144.09	172.22
Yield (tons/acre)	29.92	29.90	30.08	30.82
Tomatoes				
Acres (% total)	9%	9%	9%	9%
Applied Water (feet)	2.99	3.03	2.92	2.95
Irrigation Efficiency (%)	85%	83%	86%	85%
Irrig. tech & mngmt costs ($/acre)	139.12	129.67	145.80	140.07
Yield (tons/acre)	32.70	32.69	32.70	32.69
Wheat				
Acres (% total)	7%	7%	7%	7%
Applied Water (feet)	2.03	1.91	1.97	1.92
Irrigation Efficiency (%)	79%	83%	81%	83%
Irrig. tech & mngmt costs ($/acre)	88.29	97.37	93.27	96.30
Yield (tons/acre)	3.02	3.02	3.02	3.03
Fallow Acres (% total)	3%	2%	0.43%	8%
Collected Drain Water (af/dr. acre)	0.48	0.48	0.48	0.48
Crop Returns ($/acre)	325.65	317.59	320.15	307.97
Net Returns ($/acre)	265.37	317.59	249.28	145.28

Melons make up a small portion of the crop mix regionally so the average efficiency cost of a policy of mandating irrigation efficiency levels is not large. Melons are not produced uniformly throughout the region however, so that distributional consequences may be significant with this policy. Farmers that devote relatively large portions of their operations to the production of melons and other shallow rooted salt-sensitive crops will bear a disproportionate sham of the cost of meeting regional drainage reduction goals.

Significant differences are apparent in the results of the tax and subsidy scenarios. In general, the 45% subsidy and $45/af tax combination favors production of all crops relative to the scenario with a lower subsidy and higher tax. Fallow land makes up 8% of total acreage in the latter case and less than 1% in the former. Cotton acreage is reduced by 7% and sugarbeets by 619% with 25% subsidies and a $75/af tax relative to the case that subsidies are 45% and the tax is $45/af, though melon acreage is 39% higher.

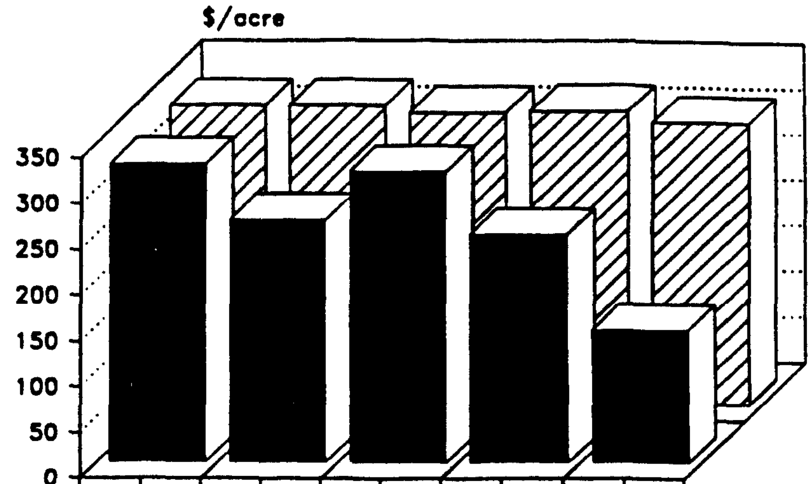
The tax and subsidy instruments result in irrigation efficiencies that are higher than optimal for all crops. The instruments effect crop-specific irrigation efficiencies differently, however. The combination with the higher subsidy rate results in higher efficiency levels, and lower water applications on cotton and melons, while the combination of a lower subsidy and higher water tax creates an incentive to increase efficiencies on sugarbeets beyond those implied by the $45/af tax and 45% subsidy combination.

Neither tax/subsidy combination is expected to be efficient because uniform rates are specified for each component of the instrument. The efficiency cost of this instrument varies with the exact combination considered. The instrument with greater emphasis on an irrigation subsidy is found to be more efficient than the instrument with a heavier weight on the water tax. Crop returns and returns net of the fiscal impacts of the policy instruments are illustrated in Figure 2. Crop returns are highest with the discharge standard and drain tax, as expected. The instrument with 45% subsidies and a $45/af water tax results in crop returns that are $5.50/acre lower than implied by the optimal solution. Efficiency costs associated with a policy of mandating irrigation efficiency levels are $8/acre, and are $18/acre for the 25% subsidy and $75/af tax combination.

Effluent (drain water) and input (irrigation efficiency) standards have no additional costs imposed at the farm-level and as a result are the instruments with the highest net returns. The net cost of the incentive instruments range from $60/acre with the drain tax to $163/acre for a policy of subsidizing 25% of irrigation efficiency costs but charging $75/af for applied water.

Results of this analysis consistently indicate low costs for meeting drainage reduction goals. These costs range from $3 per acre for achieving a ten percent reduction in drainage to $14 per acre for thirty percent reductions. One of the reasons that these costs are low is that they are averaged over the entire drainage study area, although drain systems have been installed in only two thirds of the area modeled. The average cost of meeting drainage reduction goals would increase somewhat if these costs were borne solely by farms in drained areas. The difference would not significantly effect the general results, however.

Figure 2. Crop returns and fiscal effects of alternative policies for achieving a 30% reduction in drain water



	Standard	Tax	IE Standard	Taxes (−45..45)	Taxes (−75..25)
Crop Returns	326	326	318	320	308
Fiscal Cost	0	−61	0	−71	−163
Net Returns	326	265	318	249	145

IV. Summary and Conclusions

This paper summarizes an analysis of incentive- and control-based policies for regulating agricultural pollution in California's San Joaquin Valley. The problem arises in the irrigated element-rich soils of the west slopes of the Valley. As these soils are irrigated, salts and naturally occuring trace elements are leached out and travel laterally through substrata until they empty into canals, the San Joaquin River, or in other low lying collecting basins. Salts and other elements can concentrate and bioaccumulate and cause deformities in wildlife and waterfowl. As a result of the discovery of deformities in waterfowl, California's Water Resources Control Board established water quality standards in the San Joaquin River. This study analyzes the impacts of various means of meeting these standards.

The model utilized here is a combined economic/hydrological model designed to simulate farmer decision making under various regulatory scenarios. The principle behavioral choices are assumed to be cropping patterns, applied water, and irrigation/water management technology. These are modeled under a diversity of conditioning factors calibrated to various subregions in the drainage area including: soil characteristics, weather, depth to water table, soil salinity, district water allocations and prices, plant yield characteristics, etc. A range of policy options is considered, including: effluent taxes, irrigation efficiency standards, water markets, and input tax/subsidy schemes.

Ordinarily, empirical analysis of non-point source pollution is difficult because there are multiple input and output points which are (by definition) impossible or difficult to measure. In the case examined here there are two fortunate differences. First, the hydro-physical system has been intensively modeled and hence there is information about input/output relationships. Second, the mitigating activities of installing drain systems have effectively converted a first stage non-point source problem into a second stage point source systems at the sumps. Thus unlike a pure non-point source system, it is possible, in principle, to tax effluents at the outfall in any given area. It is still difficult at this stage to accurately trace subsurface flows and correct for inter-cell externalities.

Our approach has been to consider each of 16 heterogeneous cells a decision making unit. Policies are examined in terms of their effects on the cell-specific generation of drainage and the economic efficiency and equity consequences. Of particular interest is the comparison between information-intensive, high transactions cost efficient policies (such as effluent taxes and cell-specific standards) and more broad brush and less efficient second best policies (such as input taxes/subsidies and water markets).

Results indicate that the range of pollution reduction targets currently under consideration is likely to be feasible using several policy options. The recommended 30% aggregate drain flow reduction can be achieved with irrigation efficiency standards, a uniform or non-uniform water tax, a water market, drainage standards, or effluent taxes. Different policies have different efficiency and equity implications, of course. The least cost solution involves a cost of about $14 per acre over the base case on average, achieved primarily by improving irrigation efficiency by 8-10%. This could be induced with an effluent fee of about $190 per acre foot of collected drain water or a cell-specific standard. Both policies would be costly to initiate, monitor, and administer. A second best policy easier to implement and manage would be a uniform water (input) tax. This policy is less efficient costing $30 per acre in efficiency losses over the effluent standard and it also would be fiscally onerous. To achieve a 30% drainage reduction with a uniform water tax, a tax of about $90 per acre foot of water would have to be levied. It is thus likely that some sort of offsets are necessary to make these viable, such as tiered water pricing, water tax/irrigation efficiency subsidies, or lump sum rebates. Wichelns (1991) has examined tiered water pricing and we analyze a combined water tax/irrigation efficiency subsidy. For the case where water is taxed at $45 per acre foot and irrigation costs are subsidized at a 45% rate, drainage reduction of 30% can be achieved. The efficiency costs are about $17/acre over the effluent tax case but net returns are significantly below the base case (about $90/acre). Thus further investigation needs to be devoted to analyzing schemes that improve efficiency at acceptable fiscal costs.

We thus also examine a water market as an instrument that could generally improve efficiency of water use, reduce drainage, and perhaps prove distributionally superior to tax schemes. Our model suggests that a water price of about $60 per acre foot would achieve an efficient initial redistribution within the drainage problem area and begin to free up water that could be sold outside. At this price average crop returns increase by about $18 per acre, the apparent social cost of current inefficient pricing and allocation. Equally important, net returns are higher than the base. At a water price of $90 per acre foot, for example, net returns are $28/acre higher than the base case, achieved at the targeted drainage reduction of 30%.

References

Aigner, D. J. and D. S. Chu. "On Estimating the Industry Production Function." American Economic Review. 58(1968):826-839.

California, State Water Resources Control Board. "Regulation of Agricultural Drainage to the San Joaquin River. Appendix G." Sacramento, California. August 1987.

Davids, G., and T. Gohring. "Irrigation System Costs and Performance in the San Joaquin Valley" Report to the San Joaquin Valley Drainage Program. CH2M Hill, Sacramento, California. March 1989.

Feinerman E., J. Letey, and H. J. Vaux. "The Economics of Irrigation with Nonuniform Infiltration." Water Resources Research. 19(1983): 1410-14.

Letey, J., and A. Dinar. "Simulated Crop-Water Production Functions for Several Crops Irrigated with Saline Waters." Hilgardia. 54(1986). January.

San Joaquin Valley Drainage Program, Interagency Study Team. Technical Information Record. "Overview of the Westside Agricultural Drainage Economics Model (WADE) for Plan Evaluation." Sacramento, California. October, 1989.

Weinberg, M.J., Economic Incentives for the Control of Agricultural Non-Point Source Water Pollution, Unpublished Ph. D. Dissertation, University of California, Davis. 1986.

Wichelns, D. "Increasing Block Rate Prices for Irrigation Water Motivate Drain Water Reductions" In The Economics and Management of Water and Drainage in Agriculture by A. Dinar and D. Zilberman, ed. In press.

SUBSIDIZING AGRICULTURAL NONPOINT-SOURCE POLLUTION CONTROL: TARGETING COST SHARING AND TECHNICAL ASSISTANCE

by

Erik Lichtenberg, Ivar E. Strand, Jr. and Billy V. Lessley

Department of Agricultural and Resource Economics
University of Maryland
College Park, Maryland 20742

Working Paper No. 91-10

April, 1991

This research was supported by the Maryland Department of Agriculture and by the Maryland Agricultural Experiment Station Competitive Grants Program. Presented at the AERE Workshop on the Management of Nonpoint-Source Pollution, Lexington, KY, June 5-6, 1991.

SUBSIDIZING AGRICULTURAL NONPOINT-SOURCE POLLUTION CONTROL: TARGETING COST SHARING AND TECHNICAL ASSISTANCE

Introduction

As concern over nonpoint-sources of water pollution has risen, agricultural sources have increasingly become a focus of policy. One reason is that agricultural sources account for a large and growing share of pollutants such as nitrogen, phosphorus, pesticides and (in cases like the San Joaquin Valley, California) heavy metals. Recent estimates suggest that surface water damages from soil erosion and associated runoff of agricultural chemicals in the United States were on the order of $9 billion annually (Ribaudo). Groundwater contamination by leaching of agricultural chemicals has also become a serious concern nationwide (Patrick, Ford and Quarles).

Pollution from agricultural runoff is of special concern in the Northeast and Mid-Atlantic regions, where surface and ground waters are heavily used due to high population, so that damages from nutrient and pesticide pollution from agriculture tend to be very high. Ribaudo estimated that these regions incurred 23 percent of total offsite damage from soil erosion nationwide. Estimated damage per ton of soil eroded was $5.12, almost twice as high as damage per ton of soil eroded in the second highest region.

The traditional approach to soil erosion and agricultural runoff problems in agriculture has been to promote so-called “best management practices” (BMPs), defined as cultural practices that reduce soil and nutrient losses at reasonable cost. The U.S. Department of Agriculture (USDA) and agricultural experiment stations across the country have expended considerable effort developing, testing and adapting BMPs to local conditions. Moreover, a substantial share of the technical assistance provided to farmers by state cooperative extension services has been spent demonstrating the uses of BMPs and helping farmers incorporate BMPs into their production operations.

Until recently, adoption of BMPs has been strictly voluntary. Government policy has concentrated on developing BMPs, persuading farmers to adopt them and providing technical assistance to farmers wishing to adopt. Growing concern over agricultural nonpoint-source pollution, however, has led to some changes, notably the introduction of the “conservation compliance” provision of the 1985 farm bill, which requires farmers to use farming practices in accordance with conservation plans approved by the Soil Conservation Service (SCS). Failure to comply results in ineligibility for all agricultural benefits. Full compliance was required by 1991. To ease the burden of compliance, the bill created a program that reimburses farmers for a portion of the cost of installing approved BMPs. Under this Agricultural Cost Sharing (ACS) program, the federal government reimburses farmers for 50 to 75 percent of the cost of installing BMPs whose plans have been approved by the local SCS office. States may add funds to increase the cost share rate.

Economists have long argued that subsidies are a poor policy instrument for pollution control. Baumol and Oates noted that because subsidies increase the rate of return in the polluting industry, they eventually lead to expansion of the industry. If the subsidies attract enough new investment, total pollution may increase even though each firm is polluting less than previously. The corresponding case in agriculture is that subsidizing soil conservation and runoff control measures may make it profitable to cultivate land so highly erodible that it would have otherwise been left as pasture. Erosion and runoff will increase on this land and, if a sufficient quantity is brought under cultivation, total agricultural nonpoint-source pollution may actually increase. Theoretical considerations, then, suggest that measures such as fertilizer taxes or regulations mandating the use of animal waste storage facilities and other runoff control measures would be more efficient ways of controlling agricultural nonpoint-source pollution.

Why, then, are subsidies such as cost sharing and technical assistance for installation used in agriculture? The principal problem appears to be that of financial hardship imposed on farmers, especially small farmers, who may lack the collateral or the cash flow to finance or support investment in the runoff control structures favored by SCS. In such cases, conservation compliance might force them out of business. Alternatively, runoff control practices may exhibit economies of scale that would make them profitable for large operations but not on small ones. Such would appear to be the case for storage facilities for livestock wastes, for example (Holik and Lessley).

The literature on behavioral factors influencing adoption of new agricultural technologies in general and soil conservation technologies in particular also suggests a need for policies targeted at small farmers. It has been widely observed that small farmers are less likely to adopt new agricultural technologies, at least until their profitability is firmly established (see Feder, Just and Zilberman). One reason may be credit constraints. Another may be risk aversion: Large farmers are more likely to adopt new, riskier technologies because they can diversify more against risk (Just and Zilberman). In the U. S., several studies investigating the adoption of conservation tillage and other soil conservation measures have noted that adoption rates were higher for large farmers than small ones (Ervin and Ervin; Gould, Saupe and Klemme; Lee and Stewart; Norris and Batie; Rahm and Huffman).

This paper uses data from a 1986 survey of Maryland farmers to explore the relationship between farm size and (1) participation in the ACS program and (2) access to technical assistance in Maryland. Overall, the data indicate that both programs were used more heavily by larger farmers. This finding is disturbing. The most defensible rationale for these programs is as a means of helping small farmers maintain their competitive position. But if both programs are geared mainly toward large farmers, they may have the perverse effect of increasing the competitive advantages of large farmers and thus have negative repercussions on the structure of agriculture.

Because 1985 was the initial year of the cost sharing program, the information cannot be considered definitive and more complete study will be needed to understand fully the operation of the cost sharing and technical assistance programs in subsequent years. Nevertheless, the findings of this study point to a real need for a complete analysis of these issues.

Agricultural Nonpoint-source Pollution in the Chesapeake Bay Region

Agriculture has been a major focus of policies aimed at improving water quality in the Chesapeake Bay region for some time. Relatively high precipitation, hilly terrain, vulnerable aquifers and estuaries and heavy human use of water resources due to extensive urban areas has made water pollution problems associated with agriculture especially acute (Strand and Bockstael). It has been estimated that agricultural sources account for 57 percent of total nitrogen and phosphorus entering the Chesapeake Bay, including 60 percent of total nitrogen and 27 percent of total phosphorus (Krupnick). Geologic conditions suggest that groundwater in most areas is moderately to highly vulnerable to leaching (Nielsen and Lee) and several studies indicate strong links between agricultural activity and nitrate in drinking water wells (Bachman; Lichtenberg and Shapiro).

One of the major efforts on the part of both the Environmental Protection Agency's (EPA's) Chesapeake Bay Program and the USDA to reduce nutrient enrichment has been the provision of technical information about and cost sharing for BMPs. The State of Maryland, for example, augments federal cost sharing to provide 87.5 percent reimbursement on all eligible practices, Between 1984 and 1988, the federal-state Chesapeake Bay Program spent over $34 million on cost sharing and almost $10 million on technical assistance for BMP adoption. Together, these represented almost three-quarters of the Program's total expenditures during the period.

Small farms play a prominent role in the Chesapeake Bay region. In Maryland, for example, over one-third of all farm acreage in 1987 belonged to enterprises receiving less than $25,000 in annual farm sales, and 45 percent belonged to enterprises receiving less than $50,000 in annual farm sales. Farmers grossing less than $25,000 annually accounted for about 28 percent of total crop land and 23 percent of all cattle in the state. Farmers grossing less than $50,000 annually accounted for 39 percent of total crop land and 30 percent of all cattle. The economics of farming are clearly different for these operations than for full-time commercial farms. The average net cash return per farm from agricultural sales was negative for farms with less than $25,000 in annual sales and under $500 for farms with $40,000 to 49,999 in annual sales. (In fact, the average net cash return per farm from agricultural sales was only about $11,000 for farms with annual sales of $50,000 to 99,999 [U.S. Department of Commerce]). This suggests that programs that focus on small and part-time farmers, as cost sharing and technical assistance are presumed to be, will play a critical role in meeting targets for reductions in nutrient emissions into the Chesapeake Bay.

Data

The data used to examine the use of cost sharing and technical assistance by Maryland farmers came from a 1986 survey of 280 farmers containing information about 23 different runoff control practices. The sample was representative of the state farm population in terms of age and tenure but was weighted toward full-time commercial farmers, especially crop farmers.

The survey contained information on usage of three broad groups of BMPs. The first distinction usually made is between structural and managerial BMPs, former the referring to investments requiring significant capital outlays, the latter to changes in variable input use. Managerial BMPs are often subdivided into two groups, one consisting of practices related to soil management, the other, practices related to nutrient management. Most of the BMPs considered were eligible for cost sharing. Those that were not included minimum and no tillage, fertilizer and manure incorporation, split application of fertilizer and some cases of cover crops (e.g., double cropping with winter wheat). Structural practices included in the survey were gross- and rock-lined waterways, grade stabilization, sediment basins, ponds, troughs, spring development, waste storage structures and lagoons, terraces and diversions. Soil management practices included contour farming, stripcropping, critical area seeding, filter strips, permanent vegetative cover, wildlife habitat, minimum and no tillage and cover crops. Nutrient management practices included split applications of fertilizer and incorporation of chemical fertilizer and manure.

Information on participation in cost sharing and technical assistance programs was obtained as follows. For cost sharing, farmers were asked whether they had received cost sharing money during 1985 and, if so, for which BMPs. Twenty-nine farmers reported receiving cost sharing in 1985. Twenty had received funds for installing rock- or grass-lined waterways, the remainder for ponds. Regarding technical assistance, farmers were asked to report the number of times they had received information about soil conservation during the previous year from a variety of sources, including USDA sources (notably the Agricultural Stabilization and Conservation Service and SCS), the Maryland Cooperative Extension Service and other University of Maryland sources (abbreviated hereafter as MCES), word of mouth (friends and neighbors), print sources and other sources. The reported number of contacts was transformed into a dichotomous measure for each information source.

The survey contained information on several indicators of farm size. Acreage farmed and livestock numbers indicate technical scale of operation and wealth. In this survey, acreage included all land operated, both rented and owned, and thus reflected the scale of operation. However, since 82 percent of the respondents used in the analysis were full- or part-owners, acreage also reflects wealth to some extent. The percent of family income from farming indicates the importance of farming to the family. It may also reflect the opportunity cost of time. In particular, one would expect full-time farmers to have a lower opportunity cost of time, since there are ample periods when little labor is required on the farm. Part-time farmers, in contrast, usually have tighter time constraints and a higher opportunity cost of time in terms of forgone wages. Finally, farm sales reflect volume, cash flow and the economic activity generated by the farm in the community. [1,2]

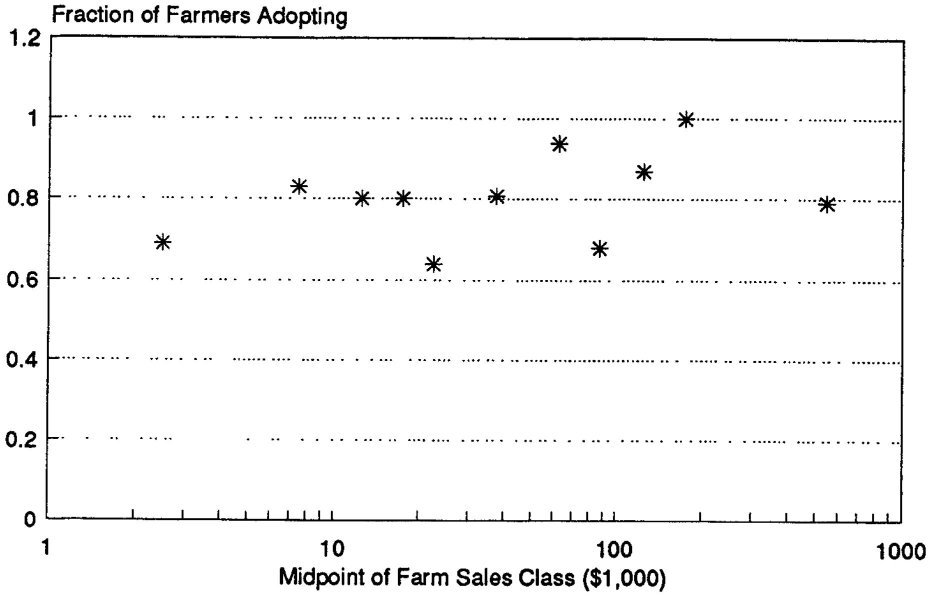
In addition to these variables, the survey also contained information on human capital (age, education, years of experience and attitudes toward environmental quality), topography (shares of land with slopes of 2-7 percent and 8 percent and up), and farm operating characteristics (the percentage of farm income derived from crops, tenure status, shares of crop acreage in corn, tobacco and soybeans).

BMP Adoption, Cost Sharing and Technical Assistance by Maryland Farmers

Figures 1 through 4 summarize some qualitative information about BMP adoption patterns and the use of cost sharing and publicly financed technical assistance as they relate to farm size. For this purpose, gross farm sales was used to measure size of operation, since it should capture much of the information from all of the other variables.

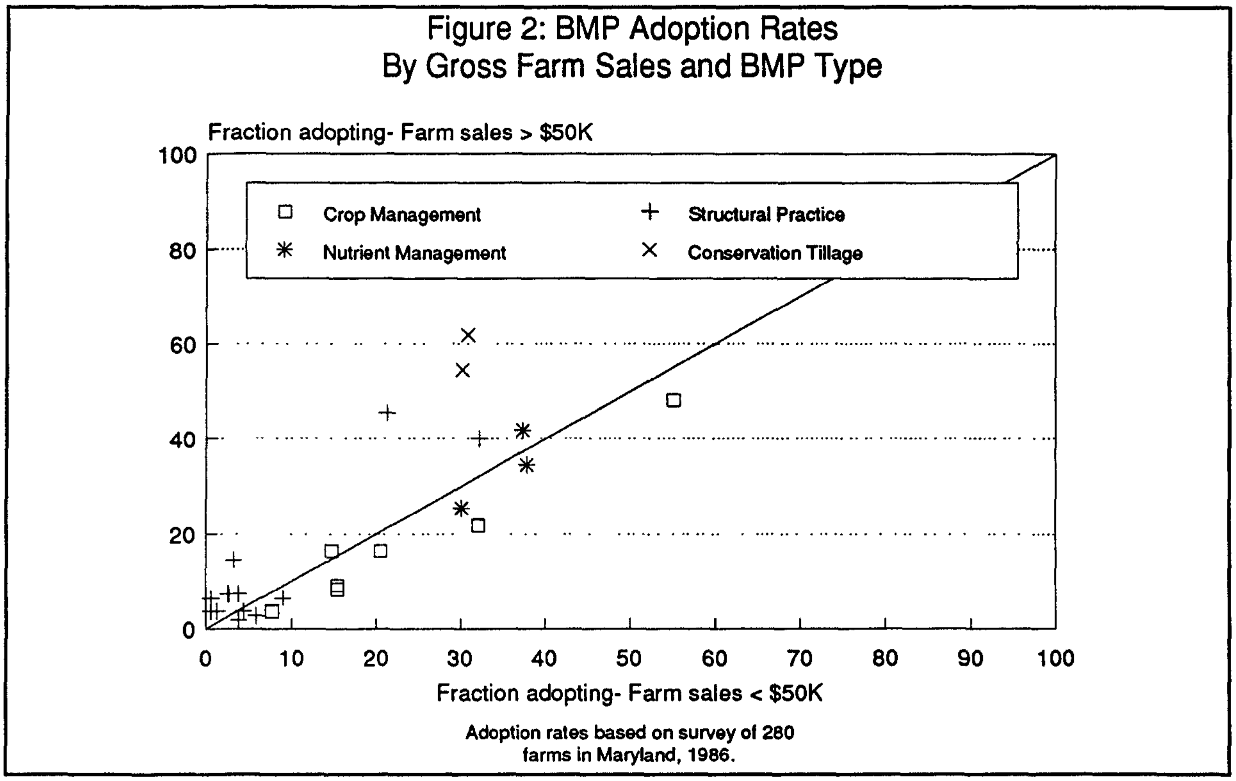
As noted above, existing empirical evidence indicates that larger farmers are more likely to adopt BMPs in the absence of cost sharing. Respondents of this survey were questioned regarding whether they had adopted BMPs without cost sharing. This information can be used to examine, in a very gross sense, the effect of farm size on relative profitability of BMP adoption, in that non-subsidized adoption rates should reflect the extent to which BMPs are believed to be profitable in and of themselves. As Figure 1 shows, a large majority reported having adopted at least one BMP without government aid. Moreover, there were no significant differences in these adoption rates as farm sales varied.[3] This suggests that, if farm size affects BMP adoption, it affects the types and numbers of practices adopted rather than whether a farmer adopts at least one BMP.

Figure 1: Fraction of Farms Adopting
BMPs Without Cost Sharing, 1985



Percentages based on a survey of 280
Maryland farmers in 1986

Figure 2 plots adoption rates for large operations, classified as those having more than $50,000 in annual sales, against those for small operations (those with sales of less than $50,000 annually). The diagonal line from the origin represents all points where adoption rates for the two groups are identical. Adoption rates for structural BMPs were on or above this line, indicating that large operations had higher adoption rates. The difference in adoption rates was especially great for grassed waterways and for waste storage structures, both of which tend to have high investment costs. As noted above, budget information suggests that waste storage structures, at least, also exhibit economies of scale. Limited and no tillage were also used much more frequently by large farmers than smaller ones: interestingly, neither is eligible for cost sharing. Adoption rates for soil management practices lay on or below the line, indicating that small operations had higher adoption rates. Nutrient management practice lay quite close to the line, indicating no difference in adoption rates.

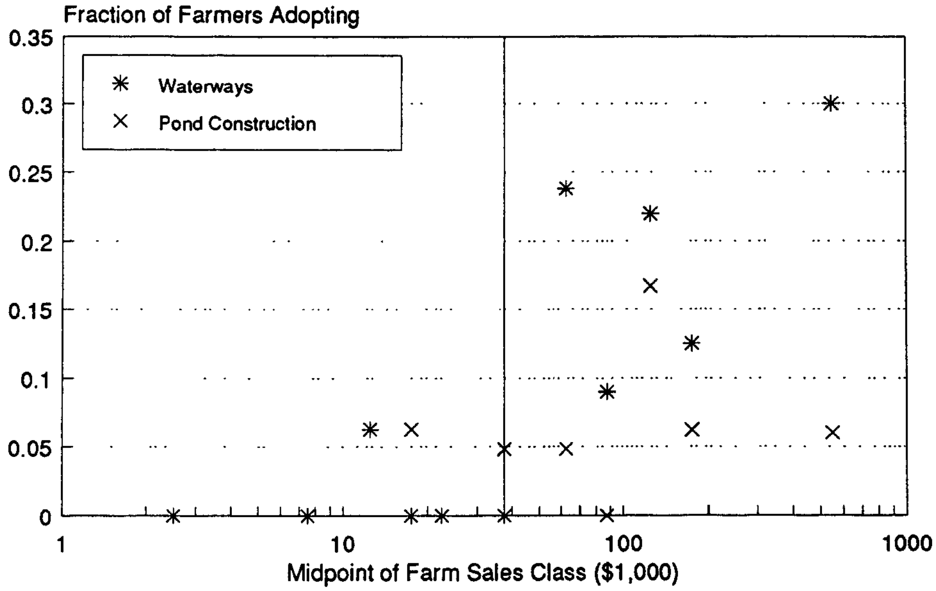


A multivariate analysis of these data performed by Lichtenberg, Strand, Lantin and Lessley confirms the patterns evident in Figure 2. They estimated a reduced form model of farmers' choices among 11 groups of BMPs using a maximum likelihood probit procedure. The results they obtained indicated that full-time farmers were more likely to use all structural practices. The use of grass- and rock-lined waterways and of ponds was not affected by acreage, indicating a lack of economies of scale.

Interestingly, their results indicated that human capital characteristics influence adoption of managerial BMPs but not structural ones. Older farmers were significantly less likely to adopt almost all managerial practices, while farmers with more experience and education were significantly more likely to use them. In contrast, human capital measures exerted no statistically significant influences on adoption of structural BMPs.

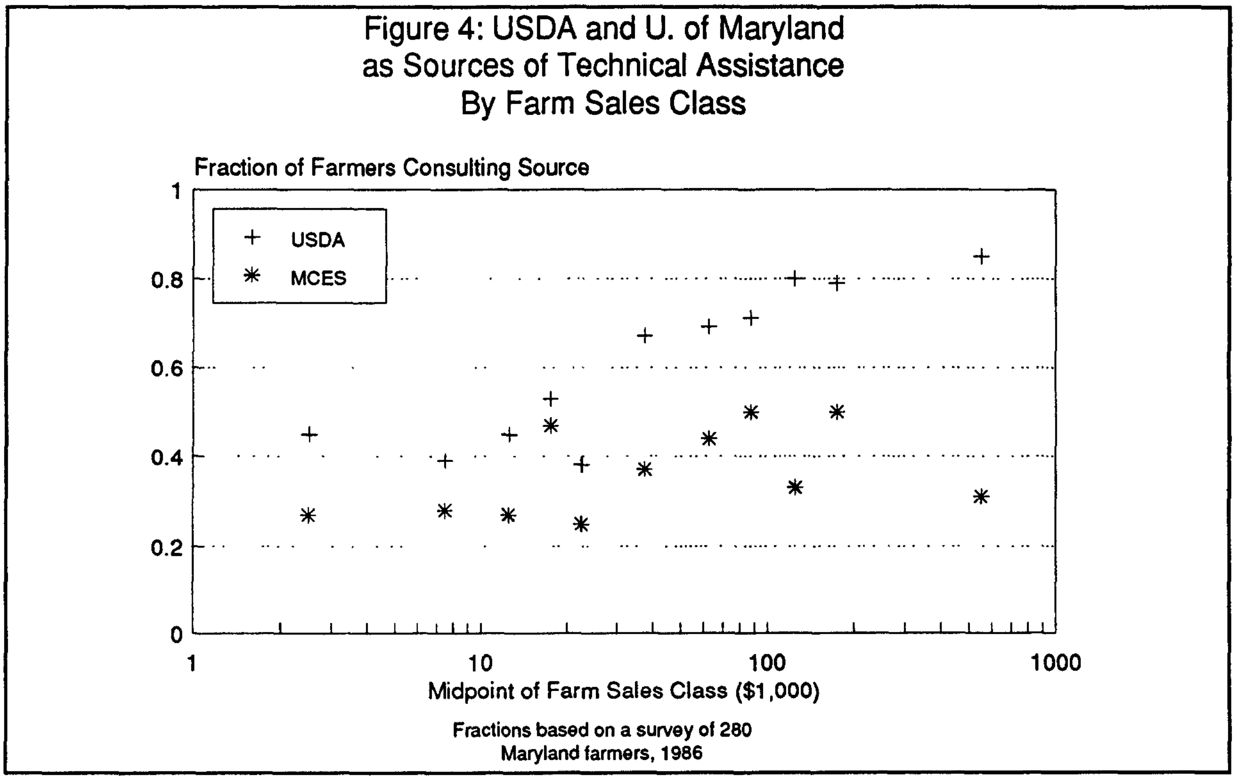
Figure 3 plots the fraction of farmers adopted BMPs with cost sharing against the log of farm sales. There is an apparent strong positive relationship between adopting with cost sharing and sales class. Moreover, this relationship appears to exhibit a threshold. Waterways, the BMP most often receiving cost sharing, had no adoption by farmers with 1985 sales less than $9,999, and almost no adoption by farmers earning less than $50,000 annually, despite the fact that they exhibit no economies of scale. On the other hand, nearly 30 percent of the farmers earning sales in excess of $200,000 received cost sharing for waterway construction.

Figure 3: Fraction of Farms Adopting BMPs with Cost Sharing



Fractions based on a survey of 280 Maryland farmers in 1986

The fraction of farmers having had some contact with the USDA and MCES are plotted by farm sales class in Figure 4. It can be seen that interactions with USDA sources about soil and nutrient conservation occurred twice as frequently among farmers in the largest sales class as among farmers in the lowest sales class. Interaction with MCES sources also increases with farm sales class but at a substantially lower rate, with the maximum fraction occurring in the $75,000-$200,000 range,



Modeling Participation in Cost Sharing and Technical Assistance

These patterns are suggestive, but need confirmation from formal statistical modeling in a multivariate framework. The farmer's decision process about whether to participate in cost sharing or obtain technical assistance was modeled as follows. It was assumed that farmers make simultaneous choices about which farming practices to adopt, whether to participate in cost sharing and whether to obtain technical assistance from federal or state agencies. Let y_{ij}^* be farmer j's expected gain from adopting practice i (or participating in cost sharing or seeking technical assistance from agency i). Assume that farmer j adopts each practice (engages in cost sharing, obtains technical assistance from agency i) for which yij* > 0. Let I_i be an indicator variable taking on a value of 1 if $y_{ij}^* > 0$ and a value of zero otherwise. Assume further that the expected gains from adoption and participation are a linear function of a set of K explanatory factors $X_i = (x_{i1}, \ldots x_{iK})$ plus a vector random components $U_i = (u_{i1}, \ldots u_{iM})$, so that the expected utility the i^{th} farmer derives from selecting the m^{th} practice or participating in the m^{th} program can be written:

$$\sum_{m=1}^{M} y_{im}^{*}\gamma_{mi} = \sum_{k=1}^{K} x_{ik}\beta_{km} + u_{im}, \qquad (1)$$

or, in matrix form,

$$Y_i^{*}\Gamma = X_i\mathrm{B} + U_i, \qquad (2)$$

where T and B are respectively MxM and KxM matrices of parameters.

This system of equations can be solved to obtain a system of reduced form relationships

$$Y_i^{*} = X_i\Pi + W_i, \qquad (3)$$

where $\Pi = \mathrm{B}\Gamma^{-1}$ and $W_i = U_i\Gamma^{-1}$. ..If the random errors in the reduced form system are distributed normally, then the reduced form coefficients Π can be estimated consistently using a maximum likelihood probit procedure (Lee). The probit procedure in SHAZAM was used to obtain these parameter estimates (white).

These reduced form coefficients contain the combined direct and indirect effects of behavioral factors on the likelihood of participation in the cost sharing program and on the use of technical assistance, and thus cannot be used to examine interactions between cost sharing, technical assistance and BMP adoption in a definitive way. Moreover, they will reflect the effects of active government outreach, which will alter the transaction costs of acquiring technical assistance differentially according to the characteristics of the farm and farm operator. For example, farmers may decide to adopt a particular BMP and use the cost sharing program after being approached by county extension, ASCS or SCS agents. The reduced form coefficients will include the effects of targeting by these agencies as well as the effects of farmers' decisions.

These coefficients will, however, indicate the net effects of behavioral factors on cost sharing and technical assistance decisions. They are thus of interest for purposes of prediction and targeting, which is the focus of the present study. What matters in this context is not the outreach patterns intended by MCES or USDA or the group targeted for receiving cost sharing, but the net effect of those programs. In other words, what matters is which groups actually received cost sharing and technical assistance. It is precisely this information that the reduced form coefficients convey.

Reduced form equations of this kind were estimated for cost sharing and for technical assistance from the U.S. Department of Agriculture (USDA) and MCES. Farm size was measured in the four ways discussed previously: Gross sales was used as the major summary measure of size; percentage of household income derived from farming was used to measure the importance of farm income (and, possibly, the opportunity cost of labor); livestock numbers (dairy, beef and poultry) indicated scale of operation and wealth; and acreage cultivated indicated scale of crop operation and, to a lesser extent, wealth. To capture the nonlinearities apparent in Figures 1-4, quadratic terms were included for all four measures of farm size. Because the linear and quadratic terms were highly collinear for acreage, percentage of income derived from farming and livestock numbers, only one was included in the final regressions. The quadratic term fit best for acreage; the linear terms fit best for percentage of income derived from farming and livestock numbers. Also included in the estimated models were human capital indicators (age, education measured by years of schooling, experience measured by years farming and reported concern over environmental quality), tenure status (a dummy having a value of one for full- or part-owner operators and zero for tenants or landlords), topography (percentages of land with slopes of 2 to 7 percent and 8 percent or greater) and cropping patterns (shares of acreage in corn, tobacco and soybeans).

The estimated coefficients for these equations are shown in Table 1.

Farm Size and Cost Sharing

It is readily seen from Table 1 that cost sharing is more heavily used by farmers with larger operations no matter which way size is measured. The probability that a farmer received cost sharing funds in 1985 increased as farm sales rose for all size classes except the largest. (The marginal effect of farm sales is negative for sales of $306,000 or greater). Farmers with larger dairy herds and farmers with greater cultivated acreage were also more likely to have received cost sharing money, as were full-time farmers.

Human capital, type of operation and topography also influenced participation in cost sharing significantly. Participation was greater among older and more educated farmers. Farmers specializing in corn were also more likely to use cost sharing. Interestingly, full- or part-owner operators appeared to be less likely to use cost sharing than tenants. There is some indication that farmers operating more highly sloped land tended to use cost sharing more as well. This may reflect the use of cost sharing for grass- and rock-lined waterways, which, according to the results obtained by Lichtenberg et al., are used more prevalently in more highly sloped areas.

Farm Size and Technical Assistance

Table 1 also shows that farmers with greater sales are more likely to obtain technical assistance from both federal and state sources. In both cases, the probability that a farmer obtained technical assistance increased as sales increased for all except the very largest. (The marginal effect of farm sales on interaction with the MCES was positive for farms with sales under $312,000; the marginal effect of sales on interaction with USDA was positive for farms with sales under $323,000.) Full-time farmers were less likely to interact with University of Maryland sources; percentage of income derived from farming had no significant effect on interaction with USDA sources. Acreage and the size of the dairy or beef herd had no effect on interaction with MCES sources. Large poultry operations, on the other hand, appeared to use MCES sources less. Livestock numbers had no discernible effect on interaction with USDA sources, but there is some indication that USDA sources had greater contact with larger crop farmers.

Human capital considerations affected the likelihood of getting technical assistance from both sources. MCES sources were consulted more often by more highly educated farmers and those reporting greater concern over local environmental quality. USDA sources were more frequently consulted by farmers with more experience.

Policy Implications

Economists have long agreed that subsidies are a poor mechanism for pollution control because they create an incentive for industry expansion and may thus even result in an increase in total pollution (see for example Baumol and Oates). In the case at hand, cost sharing might make it profitable to cultivate land that would otherwise remain in pasture or forest. If runoff from this land were sufficiently large, total nutrient and sediment loadings into waterways like the Chesapeake Bay could increase, even with reduced runoff from existing agricultural land.

In the case of agriculture, subsidies like cost sharing and publicly provided technical assistance have been justified on the grounds of assisting small family farmers who may be forced out of business by strict pollution control requirements because of inability to finance needed runoff control practices or because these practices exhibit economies of scale that make them unprofitable for small farms. Yet according to the data presented here, the provision of cost sharing and subsidized technical assistance in practice at least appear to be incongruous with that goal.

The regression results presented in Table 1 suggest that cost sharing and subsidized technical assistance were used much more by larger farmers than smaller ones. Participation in cost sharing and use of subsidized technical assistance were increasing in sales for all except the very largest operations. Full-time farmers with greater sales, more crop acreage and larger diary herds were more likely to make use of cost sharing. Farmers with greater sales were more likely to have obtained information on runoff control from MCES and USDA sources as well. USDA sources appeared to be geared especially toward crop farmers. MCES appeared to be reaching part-time farmers more successfully.

Why does this occur? With respect to cost sharing, it is possible that the cost share rate is too low to alleviate credit constraints or to make investment in runoff control profitable for small farmers. Since the current cost share rate is 87.5 percent, this reasoning would imply that cost sharing is poorly suited to small farmers and that alternative approaches need to be found.

The emphasis of the cost sharing program may also be misplaced in terms of small farmer participation. The cost sharing program is geared toward investment in runoff control structures. By contrast, Lichtenberg et al.'s results indicate that small farmers are more likely to use management practices than structural ones. Management practices place a higher premium on managerial skill and own labor than on investment funding and are thus better suited to part-time farmers with smaller sales volume. This logic also suggests that other approaches, specifically training, may be more effective in reaching small farmers than cost sharing.

Time and effort may also be significant deterrents to small farmers. Participation in the cost sharing program has high transaction costs (i.e., "red tape"). These transaction costs tend to be especially great for part-time farmers, because their opportunity cost of time is likely to be higher and because they tend to be less familiar with the operations of agricultural subsidy programs. Full-time farmers usually have a lower opportunity cost of time because of slack time at various times of the year. Larger farmers, especially crop farmers, are more likely to enroll in other agricultural programs as well, and may thus find it easier to negotiate the USDA bureaucracy. The fact that larger farmers are more likely both to participate in cost sharing and to consult with USDA sources makes this rationale quite plausible.

Another possible factor is that of cost. The cost of BMPs is also typically higher under cost sharing, because all practices must conform to SCS specifications. Even with a high cost sharing rate, it may remain cheaper to install practices that do not conform to these specifications.

Thus, smaller operators may avoid the cost sharing program even when they plan on investing in structural measures.

With respect to technical assistance programs, it is possible that USDA and MCES have concentrated on larger farmers because environmental returns appear greater: A large farm will presumably have greater production activity and more potential for pollution and thus pollution reduction. Larger farmers are often perceived as community leaders, and other farmers may follow their lead in adopting new production practices. Larger farmers may also serve as demonstrators of risky new technologies because of their greater ability to diversify against risk. It is also likely that many of the small farmers are "hobby" farmers perceived to be unlikely either to pollute or respond to BMP promotion. Alternatively, USDA and MCES outreach may focus on popularizing runoff control structures instead of management practices that smaller farmers are more likely to find attractive. Finally, the analysis may be an artifact of the data. Although it is thorough in its scope, it dates from the initial year of the cost sharing program. Since that time, these programs may have become broader in scope.

Nevertheless, these findings raise some fundamental questions about the desirability of publicly provided financial and technical assistance for runoff control when this assistance is, in practice, geared toward larger farmers. From an economist's point of view, the soundest rationale for cost sharing and technical assistance for runoff control is a concern for maintaining a desired structure of agriculture, one in which small family farms remain viable. Cost sharing and technical assistance geared toward larger farmers may even undermine such a goal by increasing large farmers' competitive advantage and thus hastening exit of small farmers from the industry.

Moreover, in regions like the Northeast it is becoming increasingly important to have policies that reach small farmers strictly from the point of view of pollution control. Small farmers account for a large share of land operated and agriculture output produced and thus, presumably, for a large share of nonpoint-source pollution as well. In Maryland, for example, 45 percent of total farm land, 30 percent of total cattle and 24 percent of corn production are accounted for by farms that gross less than $50,000 annually. The ability to reduce nonpoint-source pollution from agriculture will clearly depend increasingly on the ability to reduce runoff from small farms. Thus, policies that reach small farmers will be increasingly needed.

If in fact current policies are poorly suited for reaching small farmers, as our results suggest, then a great deal of the current approach to agricultural nonpoint-source pollution control needs to be reconsidered, Research and development effort should be geared toward runoff control measures that will be effective and acceptable on small farms. Our empirical results suggest that management practices requiring low investment and low labor input will be used more widely on small farms, especially those operated by part-time farmers. Technical assistance should be geared toward augmenting management skill on small farms. Outreach should be tailored to reach small, part-time farmers.

Getting small farmers to adopt runoff control measures may require substantial innovations in policy design. Cross-compliance generally has no effect on small farmers, because it's uneconomical for them to participate in farm programs. Small farmers are less likely to be in contact with the traditional forms of technical assistance offered by USDA and MCES. Reaching them may require these agencies to devise forms of outreach that are radically different.

As with any true innovations, the costs of creating and implementing new policies may be large. Moreover, it is not clear that the potential gains in pollution reduction would be worth the costs. However, in that case, it is also not clear that there is any real basis to continue to subsidize investment in runoff control through cost sharing and publicly provided technical assistance. Giving up on small farmers leaves no solid economic rationale for pollution control subsidies in agriculture.

In sum, the current emphases in runoff control in the agricultural research and development system may be misplaced. Development of new runoff control technologies may not be the major problem; devising policies leading to the adoption of runoff control methods, especially by small farmers, may be. In other words, perhaps at this time it would be most productive to think carefull about the real objectives of nonpoint-source pollution control in agriculture.

Footnotes

[1] Farmers were asked to classify their 1985 farm sales into one of the following groups: 1) 0-$4,999; 2) $5,000-9,999; 3) $10,000-14,999; 4) $15,000-19,999; 5) $20,000-24,999; 6) $25,000-49,999; 7) $50,000-74,999; 8) $75,000-99,999; 9) $100,000-149,999; 10) $150,000-199,999 and 11) over $200,000.

[2] Net farm income, which is difficult to measure and may not reflect fully the size of the farm enterprise in terms of volume of product or sales, was not included.

[3] The fraction of farmers adopting at least one BMP without cost sharing was regressed against the mid-point of sales in each of the eleven sales classes (with average sales for farmers grossing $250,000 and up, as reported in the 1987 Census of Agriculture for Maryland, used as the midpoint for the eleventh class) using a double-log form. The coefficient of the log of sales was 0.033 with a t-statistic of 1.23 and R^2 of 0.14.

References

L.J. Bachman, Nitrate in the Columbia Aquifer, Central Delmavra Peninsula, Maryland. Water Resources Investigations Report 84-4322, U.S. Geological Survey Towson, MD, 1984.

William J. Baumol and Wallace E. Oates, The Theory of Environmental Policy, Second Edition. Cambridge: Cambridge University Press, 1988.

Christine A. Ervin and David E. Ervin, "Factors Affecting the Use of Soil Conservation Practices: Hypotheses, Evidence and Implications", Land Economics 58 (1982): 277-292.

Gershon Feder, Richard E. Just and David Zilberman, "Adoption of Agricultural Innovations in Developing Countries: A Survey", Economic Development and Cultural Change 33 (1985): 255-298.

Brian W. Gould, William E. Saupe and Richard M. Klemme, "Conservation Tillage: The Role of Farm and Operator Characteristics and the Perception of Soil Erosion", Land Economics 65(1989):167-182.

Dan Holik and Billy V. Lessley, Dairy Production and Waste-Handling Systems on Maryland Dairy Farms, Technical Bulletin 483, Maryland Agricultural Experiment Station, College Park, Maryland, October 1982.

Richard E. Just and David Zilbelman, "Stochastic Structure, Farm Size and Technology Adoption in Developing Agriculture", Oxford Economic Papers 35(1983): 307-328.

Alan J. Krupnik, "Reducing Bay Nutrients: An Economic Perspective." Maryland Law Review 47 (1988):452-480.

Lung-Fei Lee, "Simultaneous Equations Models with Discrete and Censored Variables", in Charles F. Manski and Daniel McFadden (cd.), Structural Analysis of Discrete Data with Econometric Applications. Cambridge, MA: MIT Press, 1981.

Linda K. Lee and William H. Stewart, "Landownership and the Adoption of Minimum Tillage", American Journal of Agricultural Economics 65 (1983): 256-264.

Erik Lichtenberg and Lisa K. Shapiro, "Agriculture and Nitrate Levels in Maryland Drinking Water Wells", Working Paper No. 90-17, Department of Agricultural and Resource Economics, University of Maryland, College Park, MD, 1990.

Erik Lichtenberg Ivar E. Strand, Jr., Rhona M. Lantin and Billy V. Lessley, "Factors Influencing Adoption of Best Management Practices in Maryland", Working Paper No. 89-14, Department of Agricultural and Resource Economics, University of Maryland, College Park, Maryland, 1990.

Elizabeth G. Nielsen and Linda K. Lee, The Magnitude and Costs of Groundwater Contamination from Agricultural Chemicals. NRED/ERS Staff Report AGES8703/8, U.S. Department of Agriculture, Washington, DC, 1987.

Patricia E. Norris and Sandra S. Batie, "Virginia Farmers' Soil Conservation Decisions: An Application of Tobit Analysis", Southern Journal of Agricultural Economics 19 (1987): 79-90.

Ruth Patrick, Emily Ford and John Quarles, Groundwater Contamination in the United States Second Edition. Philadelphia: University of Pennsylvania Press, 1987.

Michael R. Rahm and Wallace E. Huffman, "The Adoption of Reduced Tillage: The Role of Human Capital and Other Variables", American Journal of Agricultural Economics 66 (1984): 405-413.

Marc Ribaudo, "Water Quality Benefits from the Conservation Reserve Program", Agricultural Economic Report No. 606, Economic Research Service, U.S. Department of Agriculture, Washington, DC, February, 1989.

Ivar E. Strand, Jr. and Nancy E. Bockstael, "Interaction Between Agriculture and Fisheries: Empirical Evidence and Policy Implications", in N.E. Bockstael and R.E. Just (cd.), Commodity and Resource Policies in Agricultural Systems. New York: Springer-Verlag, 1991, pp. 311-327.

U.S. Department of Commerce, 1987 Census of Agriculture, Volume 1, Part 20: Maryland State and County Data. Washington, DC, February 1989.

Kenneth J. White, "A General Computer Program for Econometric Methods (Version 5)", *American Statistician 41(1987):80.*

Table 1
Estimated Coefficients from Reduced Form Probit Models

Variable	Cost Sharing	University of Maryland	USDA
Constant	-8.244 (3.182)	-3.044 (2.186)	-2.141 (1.504)
Age	0.045 (2.036)	-0.003 (0.238)	-0.012 (0.988)
Education	0.174 (2.320)	0.071 (1.528)	0.030 (0.639)
Concern About Environmental Quality	-0.064 (0.168)	0.498 (1.776)	0.285 (1.008)
Years Farming	-0.013 (0.967)	0.004 (0.506)	0.023 (2.636)
Gross Sales	0.009 (1.724)	0.009 (2.454)	0.010 (2.304)
Sales Squared	-0.148×10^{-4} (1.789)	-0.148×10^{-4} (2.46)	-0.159×10^{-4} (2.164)
Percent of Income from Farming	0.025 (3.191)	-0.005 (1.572)	0.293×10^{-3} (0.085)
Cultivated Acreage Squared	0.513×10^{-6} (3.182)	-0.189×10^{-7} (0.083)	0.106×10^{-5} (1.403)
Full or Part Owner	-0.687 (1.649)	0.233 (0.840)	0.092 (0.327)
Size of Dairy Herd	0.005 (1.723)	0.455×10^{-3} (0.228)	0.001 (0.352)
Size of Beef Herd	0.006 (0.973)	0.003 (0.904)	-0.689×10^{-3} (0.217)
Size of Broiler Flock	-0.118×10^{-4} (0.800)	-0.106×10^{-4} (1.417)	-0.670×10^{-5} (0.954)
Share of Acreage in Corn	1.405 (2.235)	0.051 (0.123)	-0.128 (0.298)
Share of Acreage in Tobacco	1.496 (1.161)	-0.824 (0.794)	-0.608 (0.642)

Share of Acreage in Soybeans	-0.825 (0.881)	0.126 (0.291)	-0.083 (0.197)
Percent of Land with 2-7% Slope	0.004 (0.534)	0.002 (0.533)	0.005 (1.290)
Percent of Land with Slope 8% or Greater	0.014 (1.515)	-0.004 (0.845)	0.006 (1.199)
N	220	167	167
McFadden R^2	0.448	0.102	0.160
Absolute values of asymptotic t-statistics shown in parentheses.			

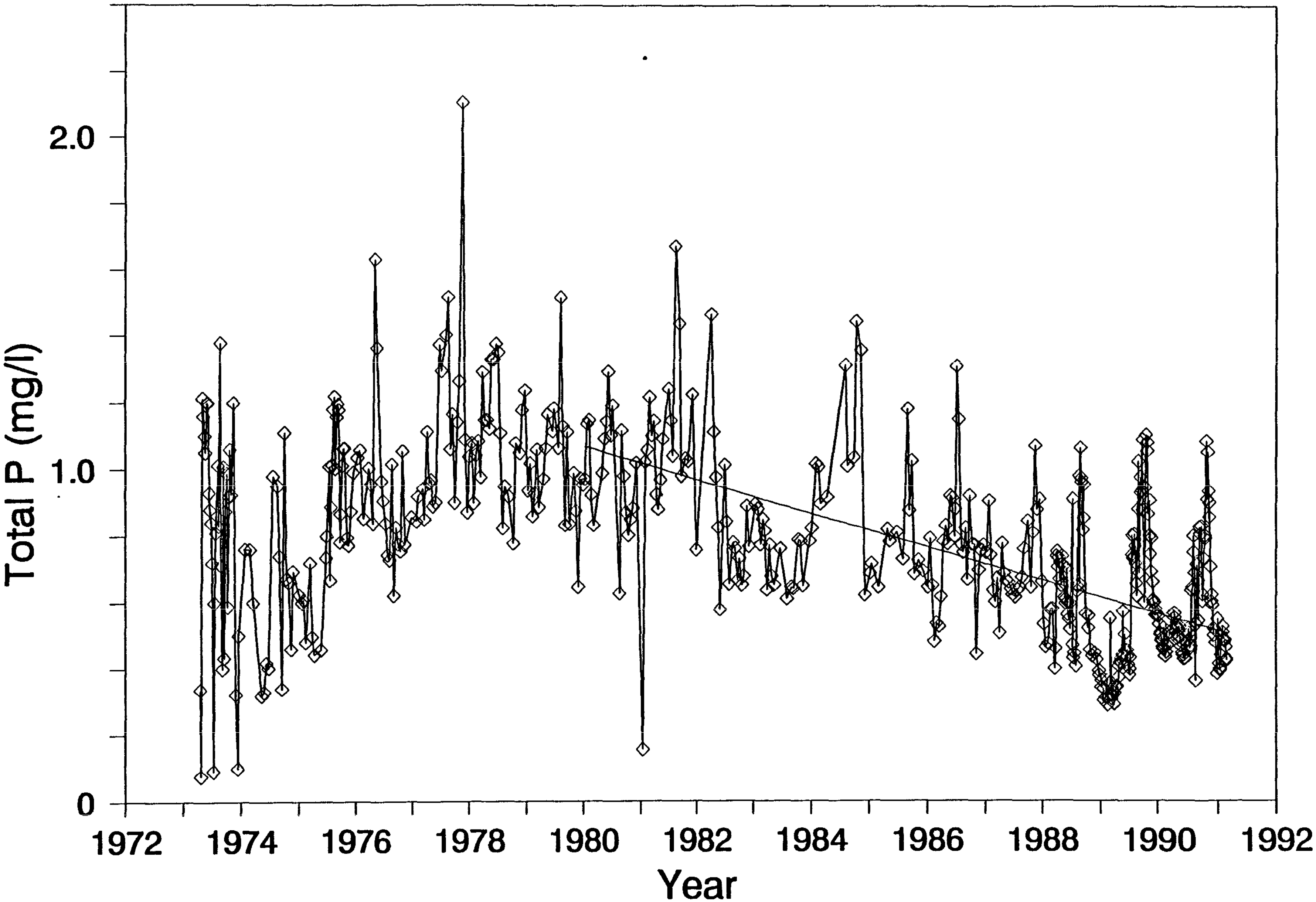


Figure 5. Total phosphorus concentration measurements for Taylor Creek-Nubbin Slough, Structure S-191, for the period 1973-1991 (trend based on seasonal medians).

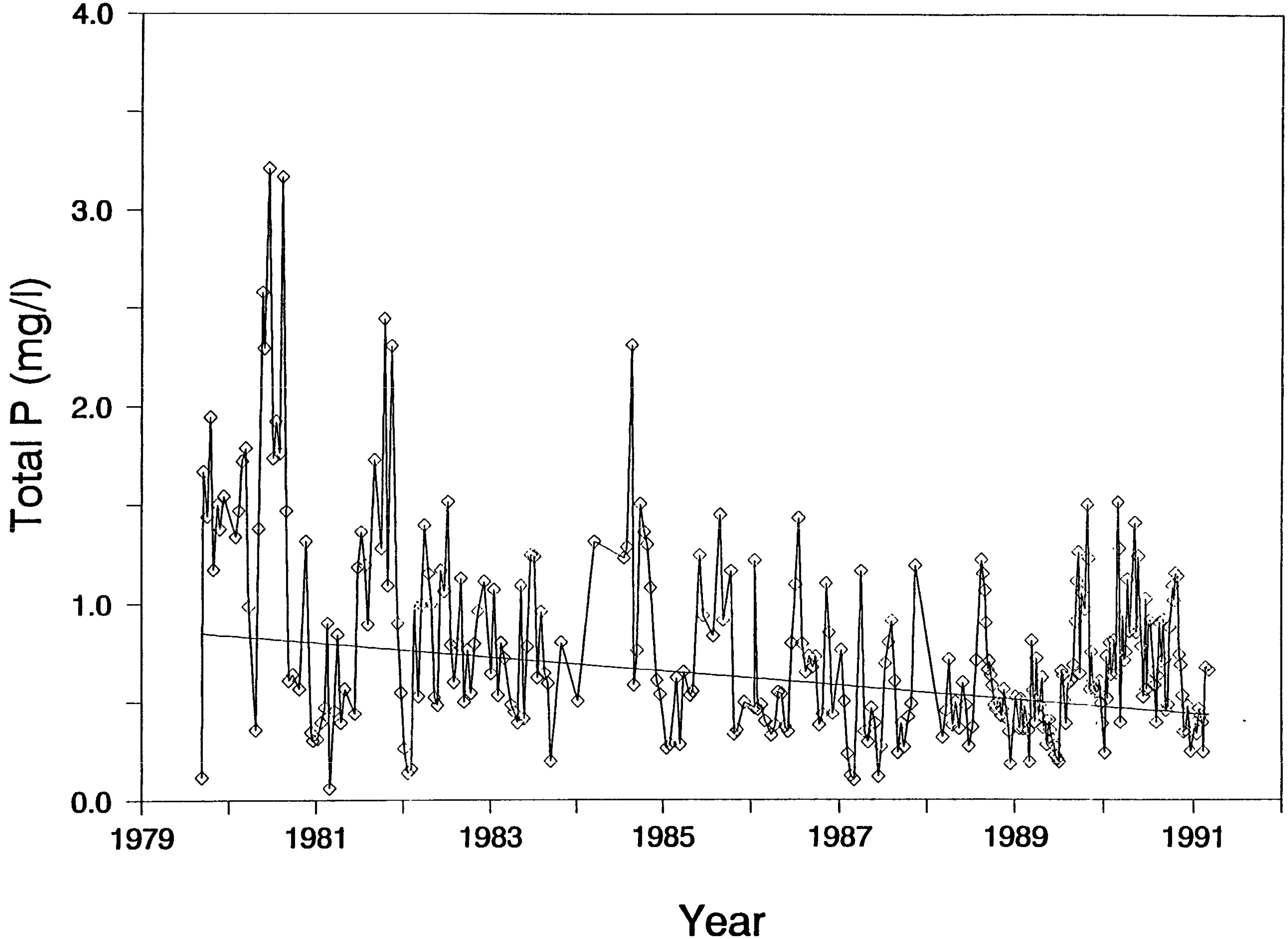


Figure 6. Total phosphorus concentration measurements for the Taylor Creek Headwaters, Structure TCHW 18, for the period 1979-1991 (trend based on seasonal medians).

Figure 13:
Cooperative weight determination game.

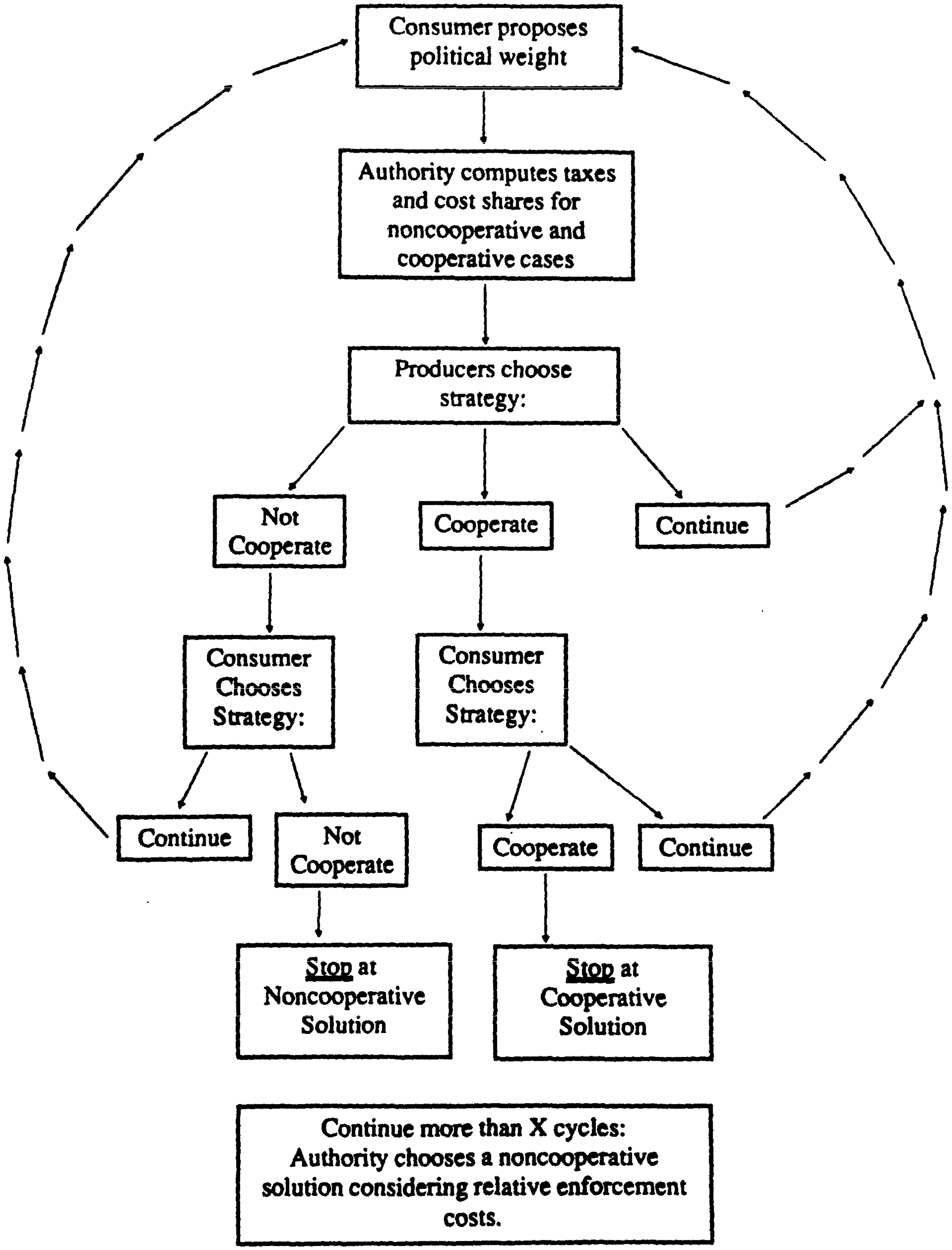
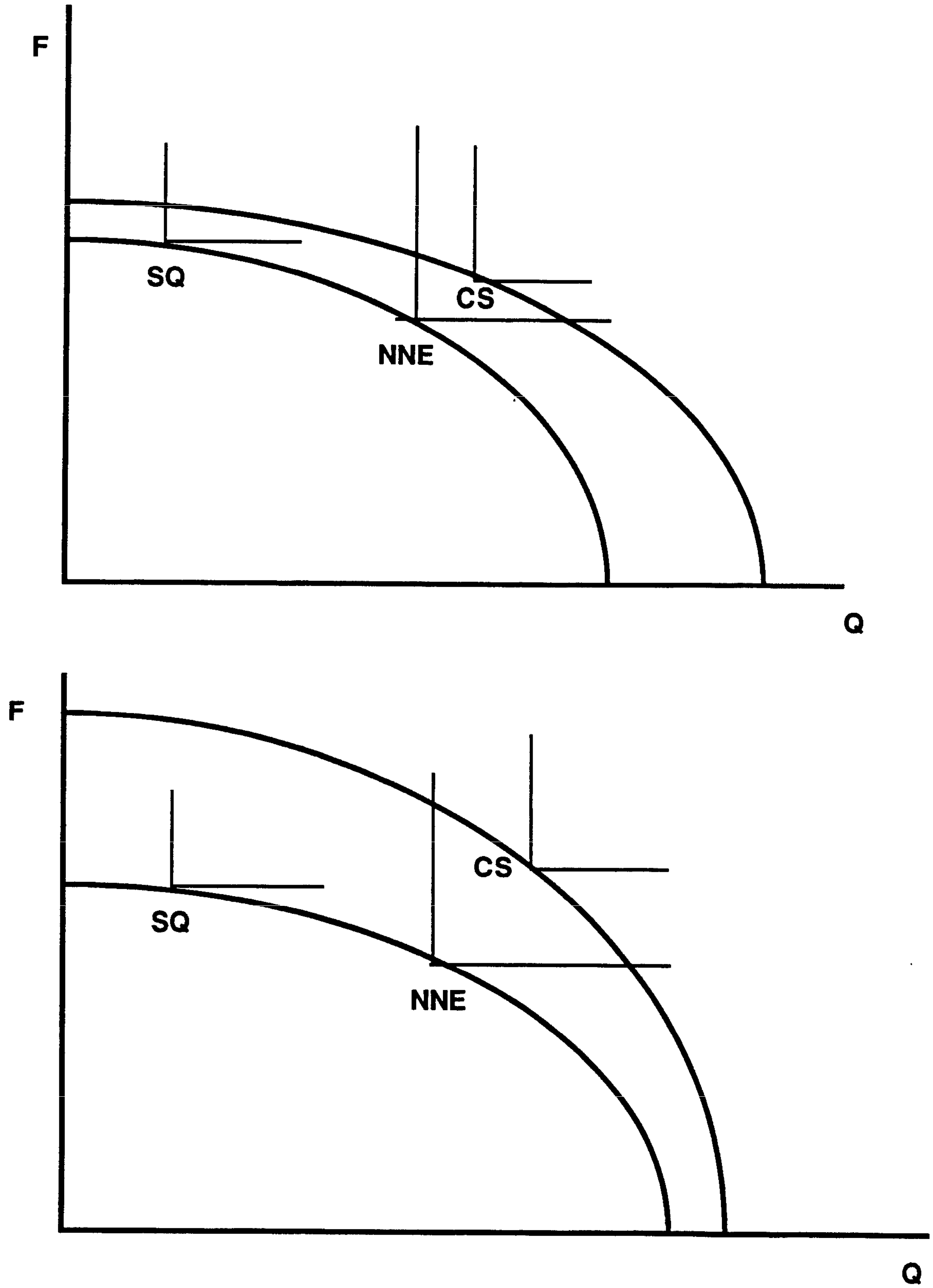


Figure 14:
A Cooperative Solution and the Corresponding NNE "Threat Point"



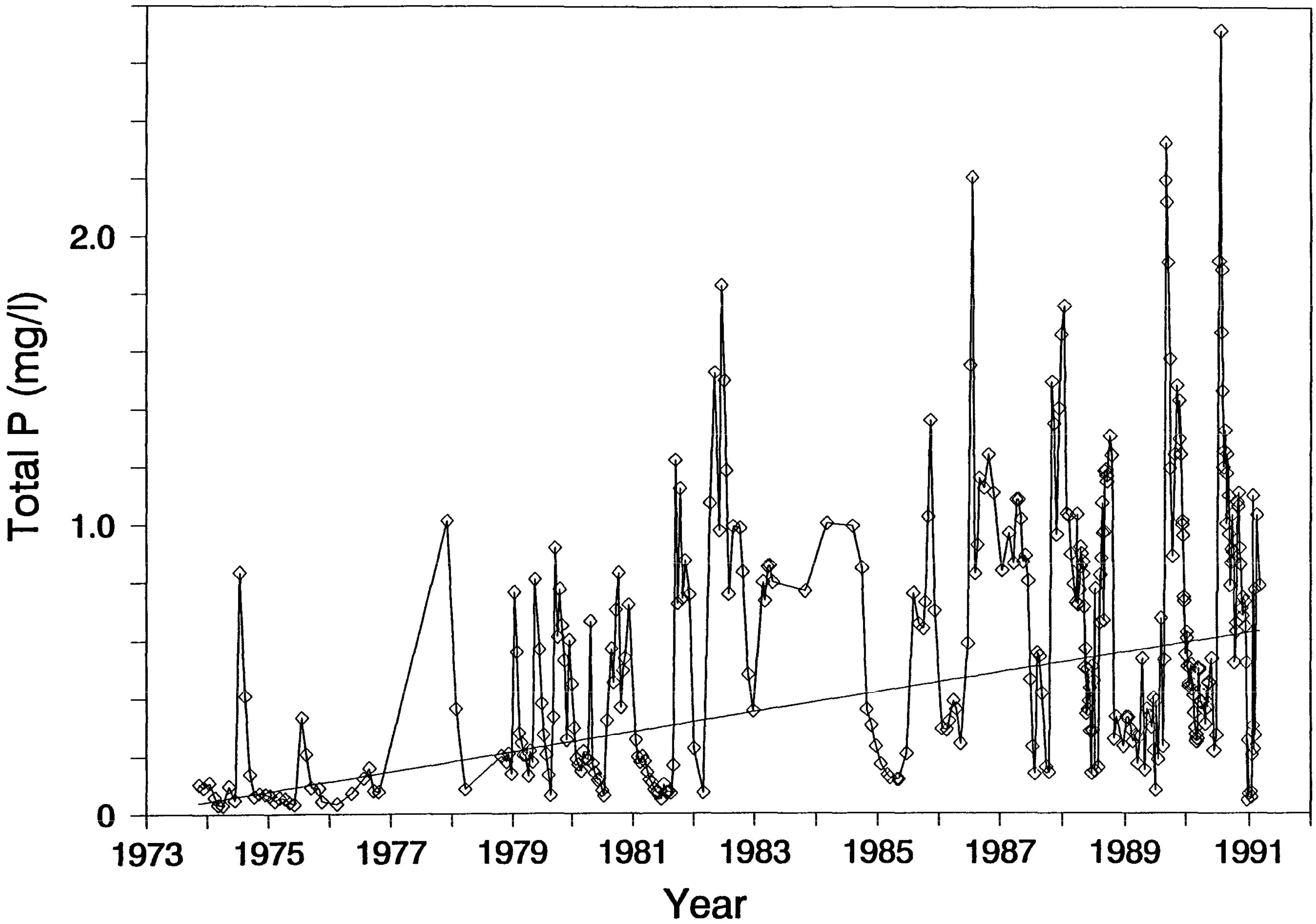


Figure 7. Total phosphorus concentration measurements for Structure S-154 in the Lower Kissimmee River Basin for the period 1973-1991 (trend based on seasonal medians).

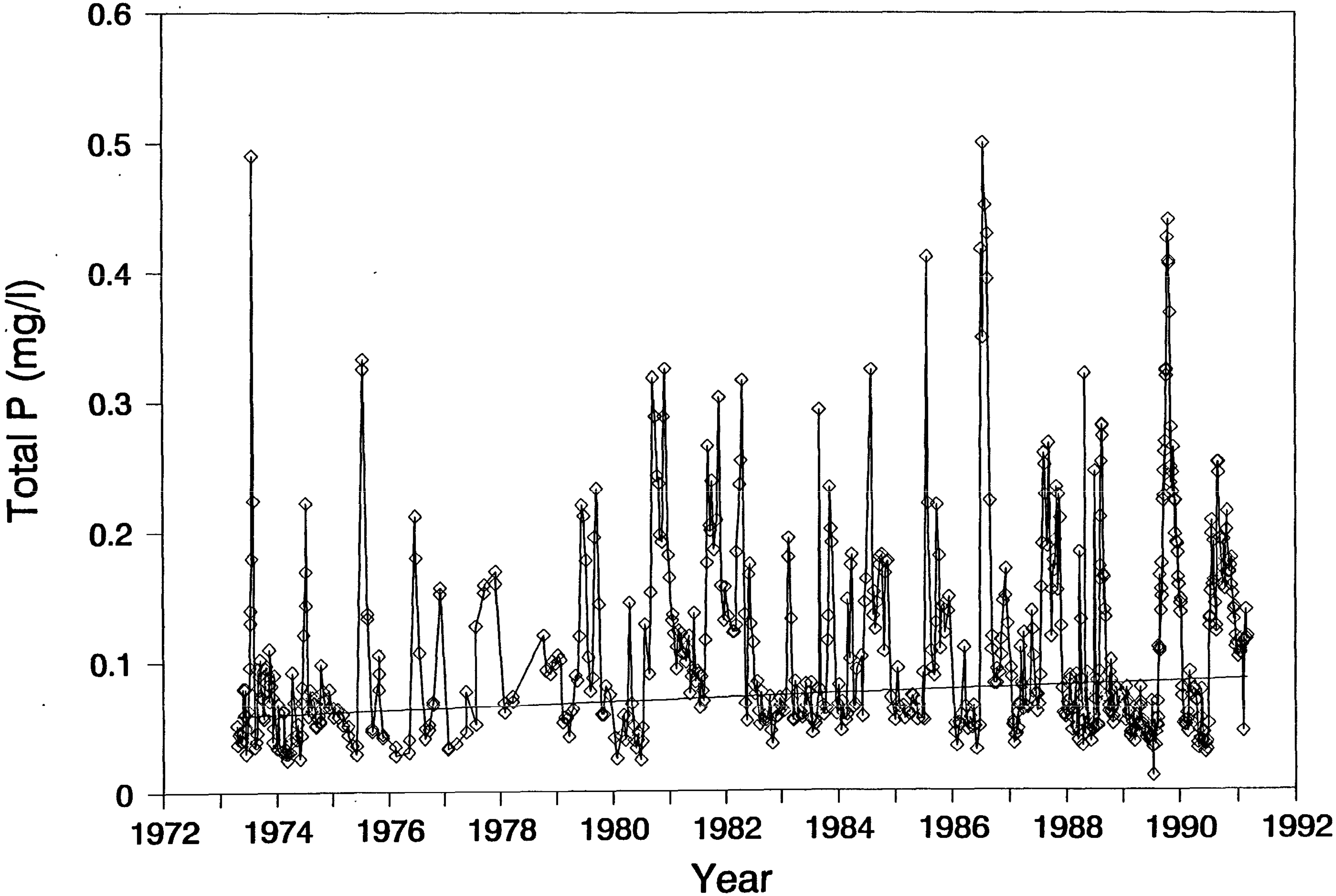


Figure 8. Total phosphorus concentration measurements for Structure S-65E in the Lower Kissimmee River Basin for the period 1973-1991 (trend based on seasonal medians).

Figure 15:
Tax on water use and Noncooperative Nash Equilibrium

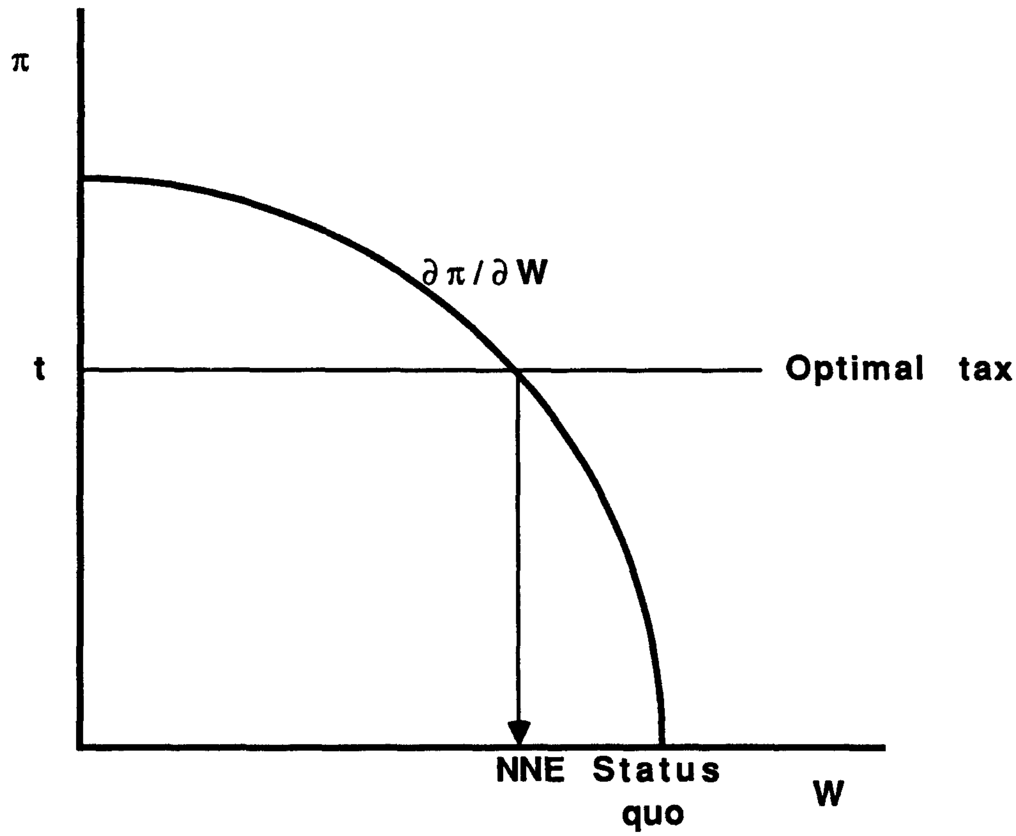


Figure 16:
Substitution between agricultural production and environmental quality in a regional setup with and without cooperation for various weights